Indian J. Phys. **52A**, 227-233 (1978)

Spin disorder scattering in nickel and iron

A A. Ghani Awad

Physics Department, Faculty of Science, Ain Shams University, Cairo, Egypt

(*Received* 28 *January* 1977)

An analysis was given for previously reported data on the temperature dependence of the electrical and thermal resistivities of spectroscopic Nickel and C-steel samples

An exponential increase of the spin disorder term in the electrical resistivity was found in the range of temperature between θ_D and T_c (θ_D-Debye temperature, T_c-The Curie temperature) The spin disorder term in the thermal resistivity reaches a maximum value at T_c Calculated Lorenz number for spin disorder scattering varies with temperature and numerically differ from that usually considered for nonmagnetic metals These results were compared with previous calculations made for Ni and Fe

1. Introduction

The paper by Sherif *et al* (1976) dealt with the design and construction of an apparatus which uses samples of small dimensions to investigate in a quick method the effect of temperature on the thermal conductivity of metals and alloys This apparatus is specially suitable for measurements around the Curie temperature of many ferromagnetic metals and alloys The results of measurement of the temperature dependence of the electrical resistivity and thersal conductivity were given for spectroscopic pure Ni and two C-steel samples.

In the present work proposed an analysis of these results in the light of previous data and theoretical works on this problem

The electrical resistivity of ferromagnetic metals display anomalous behaviour during transition from the ferromagnetic to the paramagnetic state This behaviour of the electrical resistivity was a subject of many theoretical investigations for example the works of Coles (1963), Mott (1964), Mott & Stevens (1957), Kasya (1956, 1959) and Goodings (1963) It was found that the exchange interaction between the s- and d-electrons give rise to an extra term in the resistivity. This term is generally called the spin disorder resistivity. The total electrical resistivity ρ of magnetic metals may consist therefore of three components, the lattice resistivity ρ_{ph} caused by scattering of conduction electrons due to thermal motion of atoms, the temperature independent residual resistivity term ρ_i and the magnetic resistivity term ρ_s. Weiss & Marrota (1959) using Gruneison function calculated ρ_{ph} for Nickel and Iron. We used these calculated

values to separate this component from the total resistivity and obtained the temperature dependence of ρ_s. The impurity scattering term ρ_i is negligibly small specially in the high temperature range where both ρ_{ph} and ρ_s intensively contribute to the total resistivity ($\rho_i \lesssim 0{\cdot}1$ $\mu\Omega$ CM for iron, Chari 1967). We applied these considerations to the results on the thermal resistivity ρ_T ($\rho_T = 1/\lambda$, where λ is the thermal conductivity) and obtained the temperature dependence of the spin disorder scattering term and the appropriate Lorenz number. It was found that unlike Backlund (1961) and Chari (1967) the Lorenz number for spin scattering term varies with temperature and numerically differ from the normal value.

2. Results and Discussions

1. *Electricity resistivity*

Figures 1 and 2 give the temperature dependence of ρ_s for Nickel and two c-steel samples respectively. For Nickel ρ_s tends to attain a constant value in the range higher than T_c. For iron ρ_s linearly increases with temperature higher than T_c. The rate of increase in this case is lower for the sample containing higher carbon content (0·6%). For Nickel according to the results given by

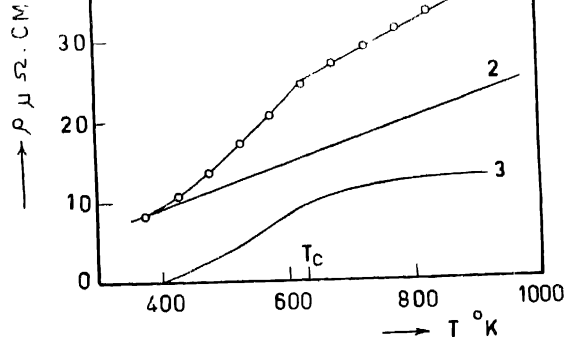

Fig. 1. Temperature dependence of the electrical resistivity in Ni-sample.
1—Total resistivity.
2—Phonon scattering term ρ_{ph}.
3—Magnetic scattering term (ρ_s).

Panakhov *et al* (1975), additives of Niobium up to 5 at % had no effect on $(\partial\rho/\partial T)$ higher than T_c. This behaviour of resistivity in Nickel and iron may be due to the different nature of ρ_s in both metals.

Two approaches were introduced to explain the behaviour of the electrical resistivity in ferromagnetic metals, the so-called band approach (or band model) given by Mott (1964) and the spin-disorder approach given by Kasuya (1956) and De Gennes *et al* (1958). According to the first approach, ρ_s is associated with

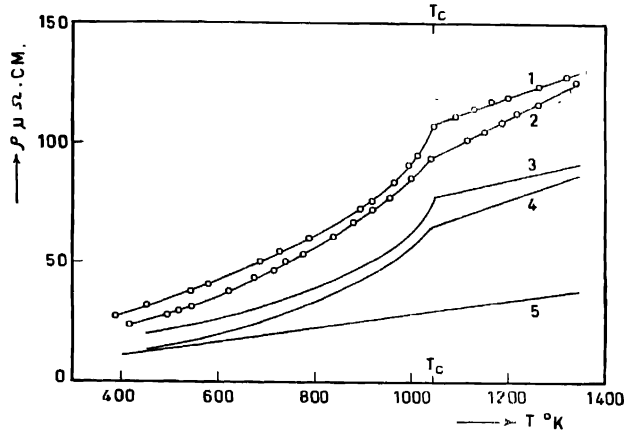

Fig. 2. Temperature dependence of the electrical resistivity for *C*-steel samples.
1—Total resistivity for 0·6% carbon.
2—Total resistivity for 0·2% carbon.
3—(ρ_s) for 0·6 carbon.
4—(ρ_s) for 0·2 carbon
5—ρ_{ph} for iron.

the increase of *d*-states available for scattering of electrons as the spontaneous magnetization decreases At the Curie temperature the spontaneous magnetization vanishes and consequently the number of *d*-states for scattering of *s*-electrons reaches its maximum value This in turn means that ρ_s attains a maximum value at T_c We may consider that ρ_s in Nickel is mainly due to this mechanism. Small additives of Nobium to Nickel slightly affects the band structure and therefore would have no effect on ρ_s in this case According to the second approach disordered magnetic moments are considered to act as additional scattering centers for conduction electrons These spin imperfections available for scattering of electrons increase with temperature having maximum effect also at the Curie temperature but still exist in the range higher than T_c. We suggest that this mechanism may give the main contribution to ρ_s in iron and consequently the non-magnetic impurity content will strongly affect ρ_s in the whole temperature range lower and higher than T_c

We tried to fit the T^3 law given by Backlund (1961) for ρ_s in iron, but our results were better fitted to an exponential lawer than to this power law The spin disorder resistivity for our Ni and Fe-C samples exponentially increases with temperature in the ferromagnetic region between θ_D and the Cuire temperature (θ_D--is the Debye temperature, $\theta_D = 456°K$ and $467°K$ for Ni and Fe respectively) It was also found that the results given by Schwerer *et al* (1970) for the temperature dependence of ρ_s in pure Ni and Fe samples also display an exponential variation with temperatrre in the range between θ_D and T_c, (see figure 3). Therefore, we may write the relation for the spin disorder resistivity for Ni and Fe in the temperature range between θ_D and T_c as

$$(\rho_s = A \exp BT)$$

where A and B are listed in table 1 From table 1 it is seen that A is about

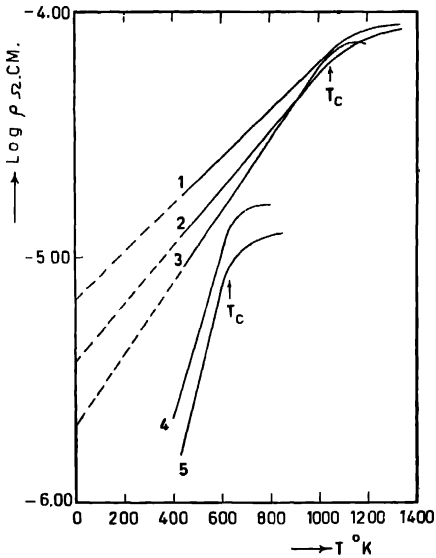

Fig. 3. Log ρ_s as a function of T.
1—For 0·6% C-steel.
2—For 0·2% C-steel.
3—For pure iron sample (Results of Schwerer 1970).
4—For pure Nickel sample (Results of Schwerer 1970).
5—For sepctroscopic pure Ni.

one-two orders of magnitudes lower for Ni than for iron and C-steel samples. This may be due to the different nature of ρ_s in Ni and Fe as pointed out in this

section. We found also that the constant B is inversily proportional to the atomic magnetic moment (μ) ($B\mu$ is nearly constant for nickel and iron samples). (μ–for Nickel is 0·6 Bohr magnetons while for iron it is 2·22 Bohr magnetons Weiss & Marrotta 1959).

Table 1. Values of A, B and $B\mu$ for Ni and Fe Samples Number 3 pure iron and number 4 pure Nickel taken from the work of Schworer *et al* 1970

Sample Number	A ($\mu\Omega$.CM)	$B \times 10^4$ ($^\circ K^{-1}$)	$B.\mu \times 10^4$ ($^\circ K^{-1}\,\mu_B$)
1	6·76	4·20	9 35
2	3 76	5·18	11·50
3	2·04	5·90	13·10
4	0·11	15·20	9·10
5	0·028	17·60	10·06

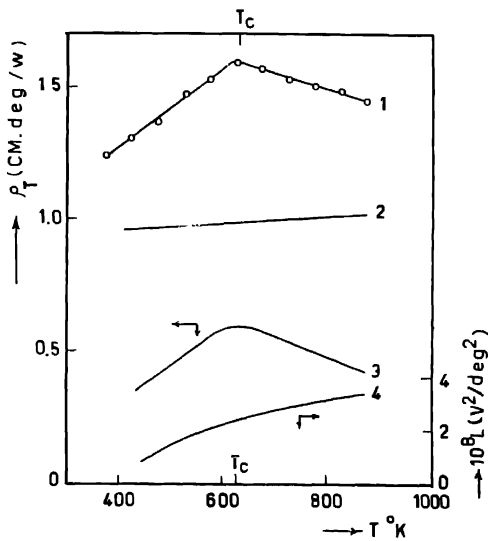

Fig. 4. Temperature dependence of the thermal resistivity in spectroscopic pure Nickel.
1—Total thermal resistivity.
2—Calculated phonon scattering term.
3—The magnetic contribution $\rho_T(s)$.
4—The Lorenz number for the spin scattering term.

II. *Thermal resistivity*

In contrary to the electrical resistivity, it is impossible in the present state of the theory to provide a completely full explanation of the high temperature thermal resistivity of transition metals (Parrott & Stukes 1975). Using the normal Weidemann-Franz Lorenz law Backlund (1961), assumed the following equation for the components of the thermal resistivity ρ_T,

$$\rho_T = \frac{\rho_{ph}}{L_n T} + \frac{\rho_s}{L_n T} + \frac{\rho_i}{L_n T} \tag{1}$$

where ρ_{ph}, ρ_s and ρ_i are the components of the electrical resistivity and L_n is the normal Lorenz number $= 2{\cdot}45 \times 10^{-8}\ \mathrm{V^2\,deg^{-2}}$ We applied this equation to our results but unlike Backlund we used the value of the normal Lorenz number only for the lattice scattering term We calculated this phonon scattering term and then by simple substraction from experimental data for the thermal resistivity we obtained the temperature dependence of the spin scattering term $\rho_T(s)$

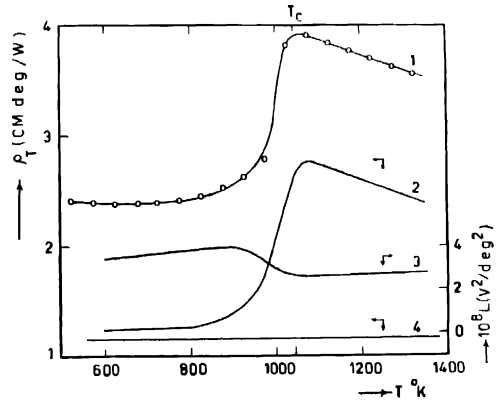

Fig 5. Temperature dependence of the thermal resistivity in 0·6% *C*-steel
1—Total thermal resistivity.
2—The spin contribution $\rho_T(s)$.
3—The Lorenz number for spin scattering term.
4—Calculated phonon scattering term.

The impurity scattering term can be neglected in the investigated range of temperature (Backlund 1961) We also neglected the lattice thermal resistivity which is generally small in metals Results are shown on figure 4 for Ni and on figure 5 for 0·6 *C*-steel sample. In both cases the phonon scattering term $\rho_T(ph)$, weakly depends on temperature The value of $\rho_T(ph)$ for the Fe sample

is 1·16 cm deg /W. which agrees with the value (1·2 cm.deg /W) calculated for iron by an independent method (Chari 1967) The magnetic scattering term in the thermal resistivity $\rho_T(s)$ for both Nickel and iron strongly depends on temperature and reaches a maximum value near the Curie temperature The maximum value being about (2 76 cm deg /W) for 0·6 *C*-steel sample agrees well with the value calculated by Chari (1967) The maximum value of $\rho_T(S)$ for nickel being only (0·6 cm deg /W) is more than four times lower than that for iron This may also be due to enhanced effect spin disorder scattering in iron than in Nickel.

Using the electrical resistivity data we calculated the Lorenz number for the spin scattering term Results of calculations (see figures 4 and 5) showed that the Lorenz number in this case is not constant as previously assumed (Chari 1967) but strongly depends on temperature and numerically differ from the normal Lorenz number usually considered for nonmagnetic metals

References

Backlund N H 1961 *J. Phys. Chem Sol.* **20**, 1

Chari M. S. R. 1967 *Phys. Stat Sol.* **19**, 169.

Coles R. R. 1963 *Adv. Phys.* **7**, 40.

De Gennes P. G & Friedel J. 1958 *J Phys. Chem Sol* **4**, 71.

Goodings D. A. 1963 *Phys. Rev.* **132**, 542

Kasuya T. 1956 *Progr. Theor. Phys*, **16**, 58.

——— 1959 *Progr. Theor Phys* **22**. 227.

Mott N. F & Stevens K. W. H. 1957 *Phil. Mag* **2**, 1364.

Mott N. F. 1964 *Adv Phys*, **13**, 325

Panakhov T. M , Pennov R. I , Muradov T. I. & Ibragimov A I. 1975 *Phys of Metal. and Metallog* (*USR*) **88**. 205.

Parrott J E. & Audrey D. Stuckers 1975 *Thermal conductivity of solids* (Pion Limited London)

Schwerer F. C. & Cuddy L. J. 1970 *Phys. Rev.* **B2**, 1575.

Sherif I I., Ibrahim A. F., Ghani Awad A. A., Ammar A. S. & Esmail S A. 1976 *Indian J. Phys* (Accepted for publication).

Weiss R. J. & Marotta A. S. 1959 *J. Phys. Chem. Sol.* **9**, 302